

COMPUTATION OF VARIABILITY IN THE AVERAGE THERMAL AND MECHANICAL PROPERTIES OF A MELT-INFILTRATED SiC/SiC COMPOSITE

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ABSTRACT

Thermal conductivity and tensile properties (elastic modulus, proportional limit strength, in-plane tensile strength, and strain to failure) of a SiC/SiC composite were experimentally determined at 816 and 1204°C. Tests were performed at room temperature on the same material to obtain interlaminar shear and tensile strengths. For each thermal and mechanical property 24 tests were conducted to capture the variation. A random sampling method was used to quantify the variability exhibited by the mean values of the thermal and mechanical properties. The minimum number of tests required to characterize the mean value of each thermal or mechanical property for the composite was determined by varying the group size of the random sample.

INTRODUCTION

Ceramic matrix composites (CMCs) are under consideration as combustor liner materials in aircraft gas turbine engines in order to sustain higher engine operating temperatures and achieve greater engine cycle efficiencies. A woven SiC/SiC composite, manufactured by a slurry-cast, melt-infiltration process, was developed as a potential candidate material [1]. Robust thermal and mechanical property data bases for the CMC are necessary for the design of combustor components. In particular, reliable estimations of the average values of thermal and mechanical properties are required from the experimentally generated data bases.

Variability exhibited in the average thermal and mechanical properties of a silicon carbide based CMC was determined as a function of the number of repeated tests with a previously developed simulation technique involving random sampling of test data [2]. The CMC investigated was the 9/99 MI SiC/SiC composite manufactured by General Electric Power Systems Composites, LLC. Test specimens were selected from three separate manufacturing lots of the CMC to incorporate lot-to-lot statistical variations. The number of tests required to estimate the average value of either a thermal or mechanical property to within ± 5 and 10% error bands was determined with the simulation technique.

MATERIAL AND EXPERIMENTAL DETAILS

For the 9/99 MI SiC/SiC composite, the fiber pre-form consisted of SylramicTM fiber woven to a 5HS weave, 20 EPI configuration with a [0/90]_{4S} lay-up. The material had a CVI silicon-doped BN interphase and a CVI SiC matrix fully densified by the slurry-cast, melt infiltration

process. Specimens for through-the-thickness thermal conductivity, tensile, interlaminar shear and tensile strength tests were machined from the as-manufactured CMC plates (dimensions: 229 mm length, 152 mm width, and 2 mm thickness). Geometry of the tensile test specimens was reported previously [3]. Interlaminar shear strength (ILSS) tests were conducted by compressively loading specimens with two notches that were offset (along the length of the specimen) whereas interlaminar tensile strength (ILTS) tests were conducted on circular disk-shaped specimens. For determining a given thermal or mechanical property of the CMC, four test specimens per plate and two plates per lot for each of the three tested lots were selected to obtain a total population of 24 specimens. Additional details on testing are available in Refs. [3-5].

THERMAL AND MECHANICAL PROPERTIES

Thermal conductivity and tensile tests were conducted at 816°C and 1204°C. ILSS and ILTS tests were conducted at room temperature (RT). Average thermal conductivity, k values at 816 and 1204°C and the standard deviations (SDs) are listed in Table I. In-plane tensile properties of the 9/99 material at 816 and 1204°C were previously reported [2, 3]. Means and SDs of four tensile properties (elastic modulus, E ; proportional limit strength, PLS (0.005% offset); in-plane tensile strength, ITS; and strain to failure, SF) at both temperatures are shown in Table I for the CMC. Moreover, average values and SDs of ILSS and ILTS at RT are also listed in Table I.

Table I
Average Values and Standard Deviations of Properties for 9/99 MI SiC/SiC Composite [$n = 24$]

Temp.	k [W/m·K]	E [GPa]	PLS [MPa]	ITS [MPa]	SF [%]	ILSS [MPa]	ILTS [MPa]
RT	---	---	---	---	---	47.2 {7.3}	15.5 {2.4}
816°C	17.6 {1.3}*	208 {14}	177 {19}	362 {32}	0.48 {0.06}	---	---
1204°C	14.8 {1.1}	182 {14}	166 {28}	307 {21}	0.46 {0.07}	---	---

* First number is mean value and the second number in {} denotes SD

SIMULATION OF GROUPS WITH RANDOM SAMPLING

Variations in the means of the thermal and mechanical properties of the CMC were computed with a previously developed simulation method [2]. For each thermal or mechanical property, the data base of 24 points represented the total population in the simulation. From this population sample groups were randomly selected and their means and SDs were calculated. Sample sizes from 3 to 12 were investigated. In the previous study [2], a total of 200 randomly selected independent groups (no duplication of data within each group) were determined to be sufficient to estimate the variability in the means for each property. The maximum and minimum means among the randomly selected groups with different sample set sizes ($m = 3$ to 12) were used to estimate the minimum number of samples required to characterize the means of the thermal and mechanical properties to within 5 and 10% of the corresponding population means (Table I).

It has been shown that the means of the randomly selected groups follow a normal distribution regardless of the distribution followed by the parent population [6]. For ILTS at RT, these distributions are shown in Fig. 1 for group sizes, $m = 4, 8$, and 12. Note the decrease in the variation of these distributions as m increases from 4 to 12. Variability in the group averages of k at 816°C are plotted against the group size in Fig. 2. Similar plots for E , PLS, ITS, and SF at

1204°C and ILSS and ILTS at RT are shown in Figs. 3 to 8, respectively. In these figures, only the maximum and minimum group averages are identified with points and the line connecting these points represents a distribution. In general, for a given property, variability in mean value decreases as the group size increases from 3 to 12. In Figs. 3 to 8, population means (μ) and error bands (± 5 and $\pm 10\%$) about μ are also plotted. Minimum number of tests needed to determine the mean thermal and mechanical properties of the CMC to within 5 and 10% of the respective population means are listed in Table II. For the MI SiC/SiC composite, at least 12 tests were required to estimate the means of thermal and mechanical properties to within 10% of the averages of the populations. However, more than 12 tests would be required to estimate the means of the properties to within 5%.

Table II. Minimum Number of Thermal and Mechanical Tests Required for the CMC Material

Temp.	Percent Error	k	E	PLS	ITS	SF	ILSS	ILTS
RT	± 5	---	---	---	---	---	> 12	> 12
RT	± 10	---	---	---	---	---	10	9
816°C	± 5	9	10	> 12	10	> 12	---	---
816°C	± 10	3	4	8	6	9	---	---
1204°C	± 5	11	11	> 12	10	> 12	---	---
1204°C	± 10	3	4	11	4	12	---	---

SUMMARY

Thermal conductivity and tensile properties (elastic modulus, proportional limit strength, in-plane tensile strength and strain to failure) of a of woven, melt-infiltrated, SiC/SiC composite (9/99) were experimentally characterized at 816 and 1204°C. Interlaminar shear and tensile strengths of the same CMC were also determined at room temperature. The minimum number of tests, required to estimate the average value of either a thermal or mechanical property of the CMC to within a certain percentage of the corresponding population average, was determined by simulating groups with random sampling. The random sampling simulation with different group sizes is applicable for any type of parent population distribution (i.e., normal, log-normal, and Weibull etc.).

ACKNOWLEDGEMENTS

This work was funded by NASA Glenn Research Center (NASA-GRC) under cooperative agreement NCC-3-1041 through the Ultra Efficient Engine Technology Program. Mr. John D. Zima conducted the tensile tests at NASA-GRC. Thermal conductivity and ILSS & ILTS tests were performed at Thermophysics, Inc. and Cincinnati Testing Laboratories, respectively.

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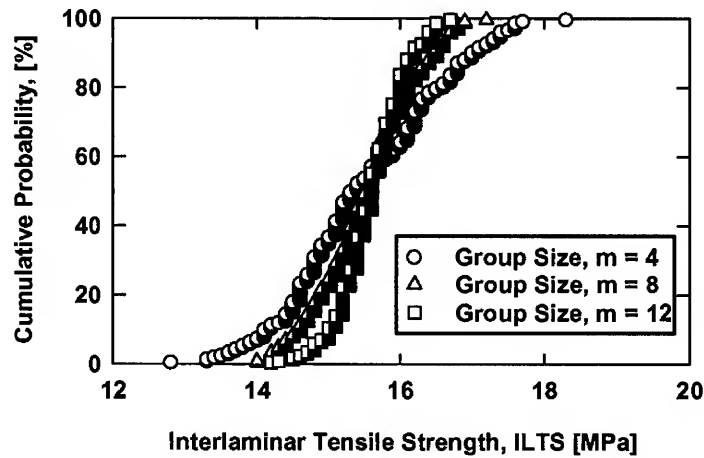


Figure 1: Distributions of the Group Averages for Interlaminar Tensile Strength at RT

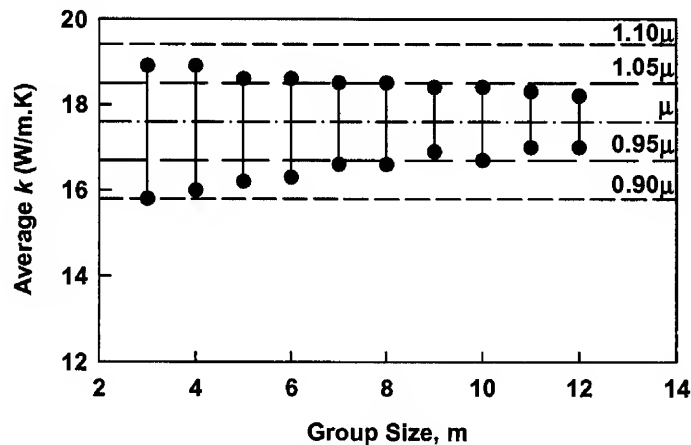


Figure 2: Variability in the Group Averages for Thermal Conductivity at 816°C

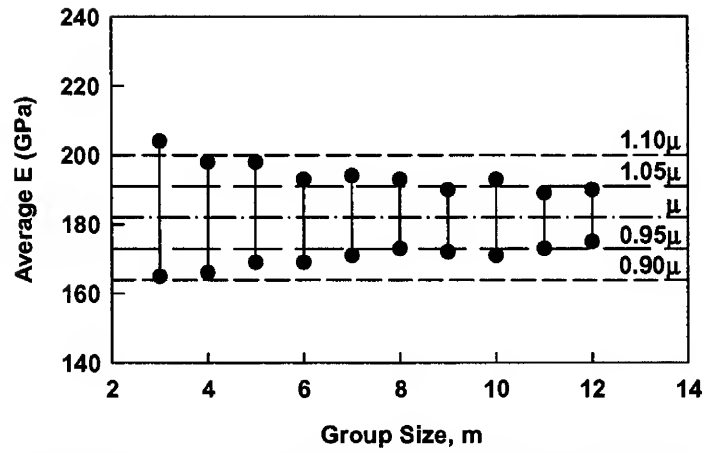


Figure 3: Variability in the Group Averages for Elastic Modulus at 1204°C

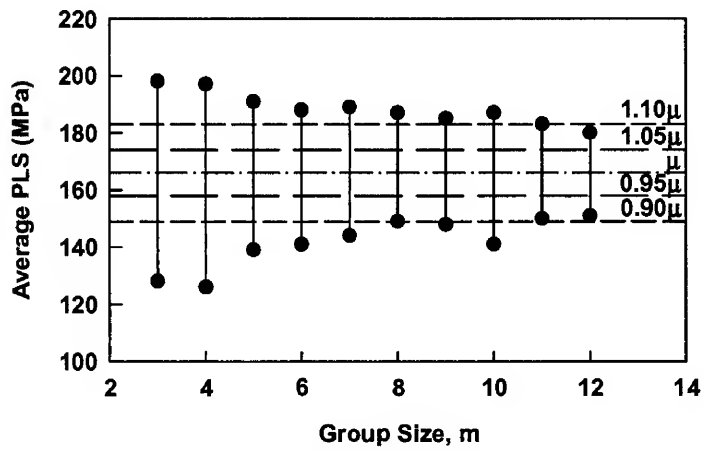


Figure 4: Variability in the Group Averages for Proportional Limit Strength at 1204°C

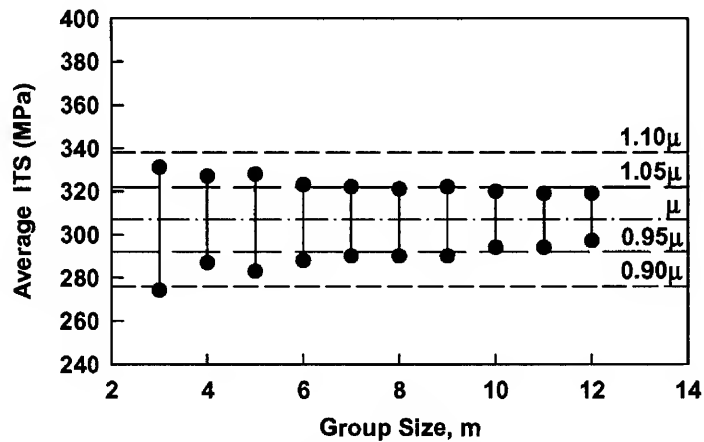


Figure 5: Variability in the Group Averages for In-Plane Tensile Strength at 1204°C

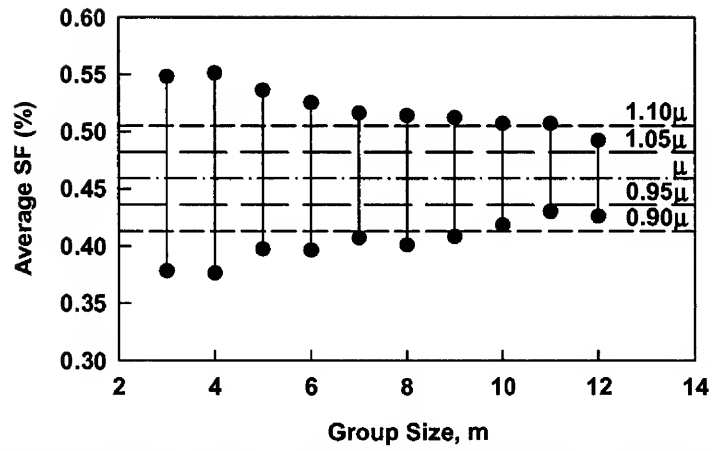


Figure 6: Variability in the Group Averages for Strain to Failure at 1204°C

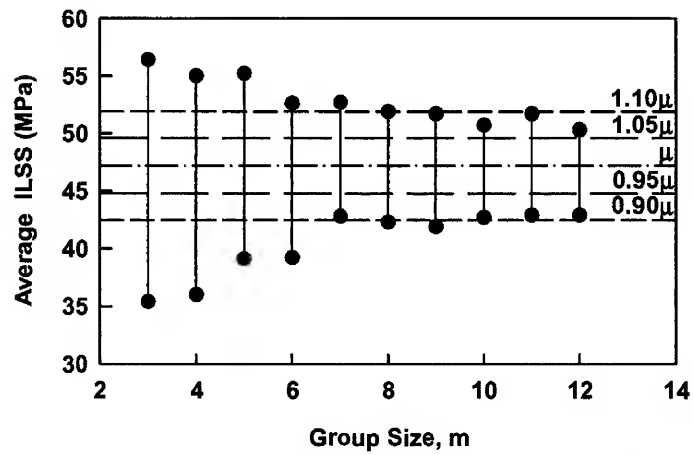


Figure 7: Variability in the Group Averages for Interlaminar Shear Strength at RT

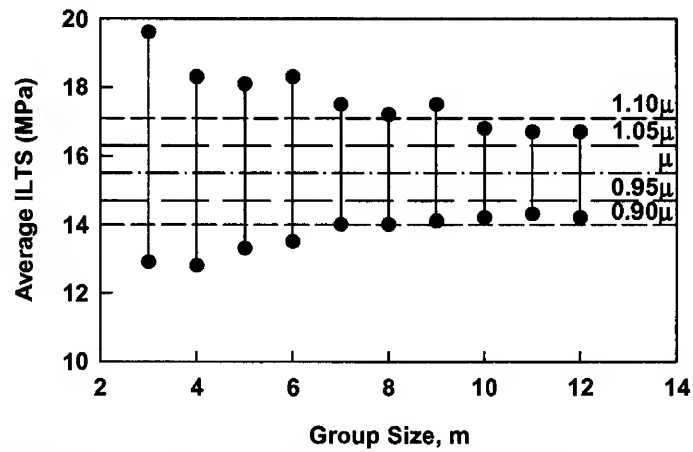


Figure 8: Variability in the Group Averages for Interlaminar Tensile Strength at RT